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THE CONSTRUCTION AND OPERATION OF SMALL PLANTS, USING LOCAL ENERGY RESOURCES, IN ISOLATED AREAS

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The construction and operation of small plants, using local energy resources, in isolated areas.

By E. W. GOLDING, O.B.E.,M.Sc.Tech.,M.I.E.E.

Introduction.

1. The need for power as an aid to development is now generally agreed. Human labour, even when assisted by that of working animals, can do little more than provide a bare subsistence standard of living except perhaps when employed in certain rural industries with products of a high cash value. For agriculture, which is usually the mainstay of an isolated area remote from centres of population, the only real hope for improvement is through increased productivity resulting from the use of mechanical power. A 1 horse power engine or electric motor is capable of doing 10 or 12 times as much work as a man, or 4 or 5 times as much as a bullock, in the same time.

2. The important question is that of providing such power at an "economic cost", defined as "the cost which will permit consumers of the energy to increase their income by an amount which is at least sufficient for them to pay for it". This will vary according to the remoteness of the area concerned, to the local availability of labour, to the methods of employment and sources of income, to the fertility of the land and possibilities of exploiting the natural resources in the area and on other factors. Although an economic balance may not be achieved immediately following the provision of a power supply, for success the ultimate result must be an overall gain in the income of the population using it.

3. Whatever the actual form of this power, it must either be imported from a distance - as power or as a source of energy from which power can be generated - or provided from local resources. Since the lower the price of the energy consumed, the greater the chance of economy, the problem in practice resolves itself into a comparison between the costs of importing it, and those of employing local sources of energy to generate it.

The costs of imported power.

4. Each of the two methods of importation tends to be expensive. The transmission of electric power involves heavy constructional costs for the transmission lines and, therefore, heavy fixed charges for interest, depreciation and maintenance. The longer the distance of transmission the higher the working voltage needed and the greater the cost, per mile. The fixed charges can be reduced to a small component of the total cost of the energy only if the total quantity supplied is large: for small

amounts of power, transmitted over relatively long distances, these fixed charges represent a major component and may bring about a prohibitively heavy cost per unit of energy supplied. Representative figures for the cost of overhead power lines for short distances - operating at 11 or 33 kilovolts lie in the range of £1000 to £2000 per mile. For extra-high voltage, long-distance transmission the cost is about ten times as much. The result is that the transmission component of the energy cost can be as much as 10 pence per kilowatt-hour, or even more, if an electricity supply with a maximum demand of only a few hundred kilowatts is to be given at a distance of two or three hundred miles from the generating station. Wise planning of a rural electrification scheme can doubtless reduce the lengths of the spur lines needed to distribute power to small villages but, until networks become much more widespread in the developing areas, supplies from local power stations will offer much better prospects of economy.

5. The commonest form of fuel-driven plant used at up-country power stations is, of course, the diesel set ranging in capacity from perhaps 10 or 15 kilowatts to several hundred kW. This is relatively economical in fuel consumption (0.5 to 0.6 pint per horse-power or 0.7 pint per kWh) but it needs skilled maintenance. Although the price of diesel fuel at the ports is usually about 15 pence per gallon, transport to inland stations may double or treble this cost and a representative generating cost at such stations is from 5 pence/kWh upwards.

6. The costs, to the consumer, of imported energy are thus usually too high to encourage consumption on anything beyond a very limited scale, perhaps for lighting and a radio set. Can local sources of energy be used as a more economical alternative capable of satisfying heavier power demands?

Power from local energy resources.

7. These local resources will usually take one of the following forms:- water power, wind power, solar radiation or waste organic matter usable as fuel. All of them have the advantages of being available free of charge and of requiring no transport from a great distance, but they have disadvantages in varying degrees.

8. Water power is very severely limited in location so that the site of a hydro-power station is precisely fixed: again, on a small stream, there may be an insufficient flow of water at some periods of the year.

9. Wind power is less confined in location, but, even so, the most favourable sites must be chosen and these may not be very close to the places where power is needed. More serious disadvantages are the very variable availability of wind power and the low specific energy content of an air stream which thus leads to the employment of a relatively large machine for a given power capacity. The exploitation of wind power may therefore call for a somewhat expensive plant which, inevitably, has a non-continuous output.

10. Plant using solar radiation suffers from much the same disadvantages as wind power: the power falling on each unit of ground surface is rather low so that, for a given capacity, the power plant must be large and relatively expensive and, also, this power is not continuously available.

11. Organic wastes, which can be used to fire a boiler for a steam engine or, alternatively, can be fermented to produce methane, serving as a gaseous fuel, are often unreliable in their quantity at the point where they are needed. If they have to be collected and transported over any appreciable distance they can no longer be regarded as a free source of energy.

(c) Assessment of the potentialities.

12. Since all of these local resources involve the provision of fairly expensive power plant - with fixed annual charges on the investment - the cost per unit of energy generated is largely dependent upon the annual output of energy likely to be obtained. An essential preliminary to their exploitation therefore, is a careful survey to determine their availability, both in time and in place, in the areas concerned.

13. The potential power capacity and annual energy output of a source of water power must be determined by measurements of water flow over a period long enough to serve as a basis for reliable estimates to be made, and these must be accompanied by assessments of the probable civil engineering constructional costs which would be required. Wind power and solar energy potentialities can be estimated fairly precisely from measurements, of wind speeds or of solar radiation, at selected, favourable, sites; again over an adequate period of time which should not be less than one year.

14. The availability of organic wastes can be determined from enquiries at their source while their energy value can be estimated from measurements of their calorific value and experimental work on their performance as producers of methane (by fermentation) or as furnace fuels.

15. The estimation of available annual quantities of energy must be accompanied by a consideration of the availability of the energy source, in time, as related to the probable purposes to which random sources may be applied. Some functions, e.g. water pumping, can be fulfilled satisfactorily at random times whereas others, e.g., lighting, demand availability at night. Storage of energy, to cover periods of non-availability of the source is usually an expensive process and is to be avoided so far as possible. If the random sources can be used as and when they occur the energy provided by them is often reasonably cheap. It is important, therefore, to consider the loads to be supplied as well as the means of supplying them.

(d) Comparative cost estimates.

16. In an endeavour to present comparative costs of energy produced by different means at a remote station, Table 1 has been drawn up. The costs for imported energy can be computed with some accuracy for any required size of plant, or of power demand, at any specified place. Those for the energy derived from local sources are certainly less accurate although the assumptions made in calculating them have been based on the latest available information from organizations concerned with the development of the relevant plant. In addition to the notes

Table 1

Comparison of energy costs.

Form of power	Distance of original source (of the energy) from point of utilization. (miles)	Maximum power demand. kW)	Approx. cost of energy per kWh (pence)	Notes of characteristics and assumptions made
Imported				
Electric, imported by overhead transmission lines.	50	500	3 to 4	Assuming annual load factor of 30% and 15% annual return on capital cost of the line.
		100	10 to 12	
	200	500	10 to 12	
Diesel-electric	50	10 to 100	2 to 3.5	Assuming fixed charges at 20%, diesel fuel costs 15 pence per gallon. Annual load factor 30%.
	200	500	4 to 5	Assuming fixed charges at 20%, diesel fuel costs 30 pence per gallon. Annual load factor 30%.
Petrol-electric	50	up to 10	7 to 9	Annual load factor 30%. Petrol cost 48 pence per gallon.
Local*				
Water power	1	up to 50	0.5 to 5	Assuming capital costs, (including civil engineering) ranging from £100 per kW to £500 per kW, fixed charges as 10% and annual load factor ranging from 25% to 50%.
Wind power	0.5	up to 5	3 to 9	Assuming an average windspeed of 12 m.p.h. and 12½% fixed charges. The upper figure allows for some energy storage.
		5 to 30	1 to 5	Cost of energy depending on annual wind speed and degree of storage.
		30 to 100	1.0 to 2.5	Assuming only limited energy storage.
Solar energy	Neglibibly small	up to 5	1 to 2	For production of heat for water heaters, water distillation, air conditioning etc.
			5 to 10	For motive power when solar engines are in production.
Organic wastes	1	2 to 10	1 to 3	For heating and cooking.
			3 to 6	For motive power from small steam engines.

* Because of uncertainties in the capital costs applicable to the required power plants when these forms of power become commonly used, the ranges of energy costs are wider than those for the more conventional forms of energy given in the preceding lines.

given in the fifth column of the table the following bases of estimation can be stated:-

(a) Water power plant. Capital cost varying from £200/kW for a 10 kW unit down to £40/kW for a 100 kW unit these costs excluding those for electrical transmission and civil engineering work.

(b) Wind power plant. Capital cost varying from £300/kW for the smallest plant (with battery storage) to £100/kW for plant of 100 kW or more in capacity.

(c) Solar energy. Cost for flat plate collectors (which form the basis of solar equipment for water heating, distillation, refrigeration and air conditioning) around £1.5/sq.foot. The energy cost for motive power production is based on information in a paper by H. Tabor (World Power Conference, Melbourne, 1962).

(d) Organic Wastes. Until the costs of collecting the fuel and those of capital cost for a small plant to utilise them, for steam raising or methane production, are known, a statement of energy costs is admittedly little better than a guess.

17. It is perhaps not unreasonable to conclude from the comparison exhibited in the Table, that energy from local energy resources may well compare favourably in cost, with that which may be imported.

Small power plants.

18. Both water- and steam-power plants are well enough established for discussion of their characteristics and performance to be omitted here when the available space is severely limited.

19. Plant utilising solar energy is being developed in several countries and work over the past ten years has already shown that solar water heaters are past the experimental stage. They can be quite economic and some thousands (8000 to 10,000 in Israel) are being installed annually. For water distillation their economy depends on the purpose for which the water is required, upon its salinity and the location of the installation. For refrigeration and air conditioning the economy is at present probably marginal but much depends on the insolation at the place concerned. The economic production of motive power from solar radiation by some form of heat engine, is still some way off in spite of strenuous efforts towards reduction of the cost of the plant needed. The direct conversion of this radiation to electric power, although technically satisfactory, is still far too expensive for use for purposes other than special ones, needing only small amounts of power which could not easily be provided by other means.

20. Research on the development of wind power has been done in Great Britain, during the last 14 years, by the Electrical Research Association. Wind surveys have been made in favourable coastal areas of the British Isles - and in several other countries, under United Nations auspices, following the British method. Several new wind-measuring instruments for the study of wind behaviour have been developed, and, following theoretical and practical studies to determine the best design, a number of pilot plants and prototypes have been built. The latest machines, of 25 kW and 100 kW capacity and built, respectively, by Dowsett Holdings Ltd. and R. Smith (Horley) Ltd., have been tested, during the last three years in the Isle of Man where they are connected to the local electricity network. Details of their construction and performance are given in Table 2 and figure I and the machines are illustrated in figures II and III.

Table 2.

Constructional details of wind-driven generators.

	25 kW machine	100 kW machine
No. of blades	3	3
Diameter of wind rotor	40 feet	50 feet
Hub height above ground	33.5 feet	35 feet
Type of electrical generator	Slip-ring induction generator, totally enclosed.	Standard squirrel-cage induction with fabricated cover.
Blade pitch	Fixed when running: coarse pitch for stopping.	Fixed. Output control by stalling of blade.
Blade construction	Main spar with ribs and aluminium skin.	Aluminium extruded sections.
Method of orientation	By fan-tail.	By fan-tail.
Method of starting	Resistance starter.	Direct-on-line starter for automatic operation. Star-delta starter for hand-starting.
Method of braking	Blades move into coarse pitch.	Disc brake actuated by de-energising a solenoid.
Re-starting after power failure	Manual.	Manual after resetting the brake.

21. It appears probable that, after a further period of running experience to determine the liability of the blades to damage from vibration fatigue and to make such design modifications as may then prove necessary, both of these machines could be made available commercially at an economic price (within the range previously mentioned in 16).

22. While there is no technical difficulty in operating a wind-driven generator connected to an a.c. network into which it feeds its random power output, the operation of an autonomous unit, without a network to maintain its rotation speed at an almost constant value, could be rather more troublesome. For stability, and to ensure full utilization of the available energy, the load should then be continuously matched, as far as possible, to the available power output. This question has been studied experimentally and successful results in operation under normal supply conditions (at an isolated house in the Scottish Highlands) have been obtained through the use of a specially-developed load distributor.

23. An alternative method, when a single load, e.g. water pumping, is to be supplied, is to connect the alternator directly to the load, driven by an induction motor. It has proved possible, by correct choice of the load and alternator characteristics, to achieve satisfactory operation in spite of the varying voltage and frequency of the alternator output caused by fluctuating wind speeds. Similar variations are likely to occur when other small power

plants, e.g. steam-driven sets, are used.

24. Non-electric, water-pumping windmills have been widely used in the drier areas of the world and they present no technical problems of operation or maintenance. Wheel diameters range from 6 ft. to 18 ft. and pumping rates - against a 100 ft. head - from 200 gal/hr. to 2000 gal/hr. in a wind speed of 14 m.p.h. Corresponding costs are 6.5 pence/1000 gal. and 2.5 pence/1000 gal. at a site with an annual average wind speed of 10 m.p.h.

) Effective utilization of local energy resources.

25. The local sources of energy being free (except, perhaps, for the cost of collecting organic wastes), the annual operating costs of the power plants used to exploit them are only the fixed charges - for interest and depreciation - and the maintenance costs, the last being usually quite small because the plants are robustly designed for automatic, or semi-automatic, operation. It follows, therefore, that the more fully the plant is used the lower the cost per unit of energy. The plant must not stand idle, or only partially loaded, when adequate power is available to it: useful loads must be found. This is the function of the load distributor already mentioned. It automatically "shunts" power to one or more of a group of selected loads, e.g. for water pumping, heating or cooling, automatic grinding of foodstuffs etc., whenever there is enough power available. These loads must, of course, be chosen from among the many which can be supplied at any time of the day or night, acting as "sinks" into which energy can be poured. They are a cheaper alternative to storage devices which, while certainly needed to cater for high-priority loads at certain specified times, undoubtedly add considerably to the cost of that part of the energy supplied through them.

26. Automatic load distribution can be done conveniently only when the power has been converted to electrical form and, although all the local sources of energy could be applied to the generation of electricity, direct utilization, without such conversion, may be more economic. An obvious example is the use of solar water heaters. It may well be, therefore, that the best way to use these sources would be in combination, allowing each source to supply the loads for which its characteristics are suited. Random sources of power such as wind or solar radiation can be "firmed" by more continuously available sources - water power or power from organic wastes which can be stored for stand-by purposes.

Conclusion.

27. The research and development work done during the last decade has proved that there is scope for the use of small, locally-powered, plants as potentially economic producers of energy. For some forms there is little more research to be done: for others much is needed. The difficulties being faced are clearly not insuperable but the application of such plants to practical purposes calls for careful consideration of (a) their design in relation to their intended location and use; (b) the combination of suitable types and sizes best suited to the requirements; and (c) the choice of sites for experimental schemes in which the use of the power by local inhabitants can, in the early stages, be adequately supervised by representatives of development authorities. The establishment of one or two experimental schemes to test the potentialities under entirely practical conditions, would provide much information which is essential if the exploitation of these local energy resources is to make any progress in the near future.

Fig. II

25 kW wind-driven generator
under test in the Isle of Man

Fig. III

100 kW wind-driven generator
under test in the Isle of Man

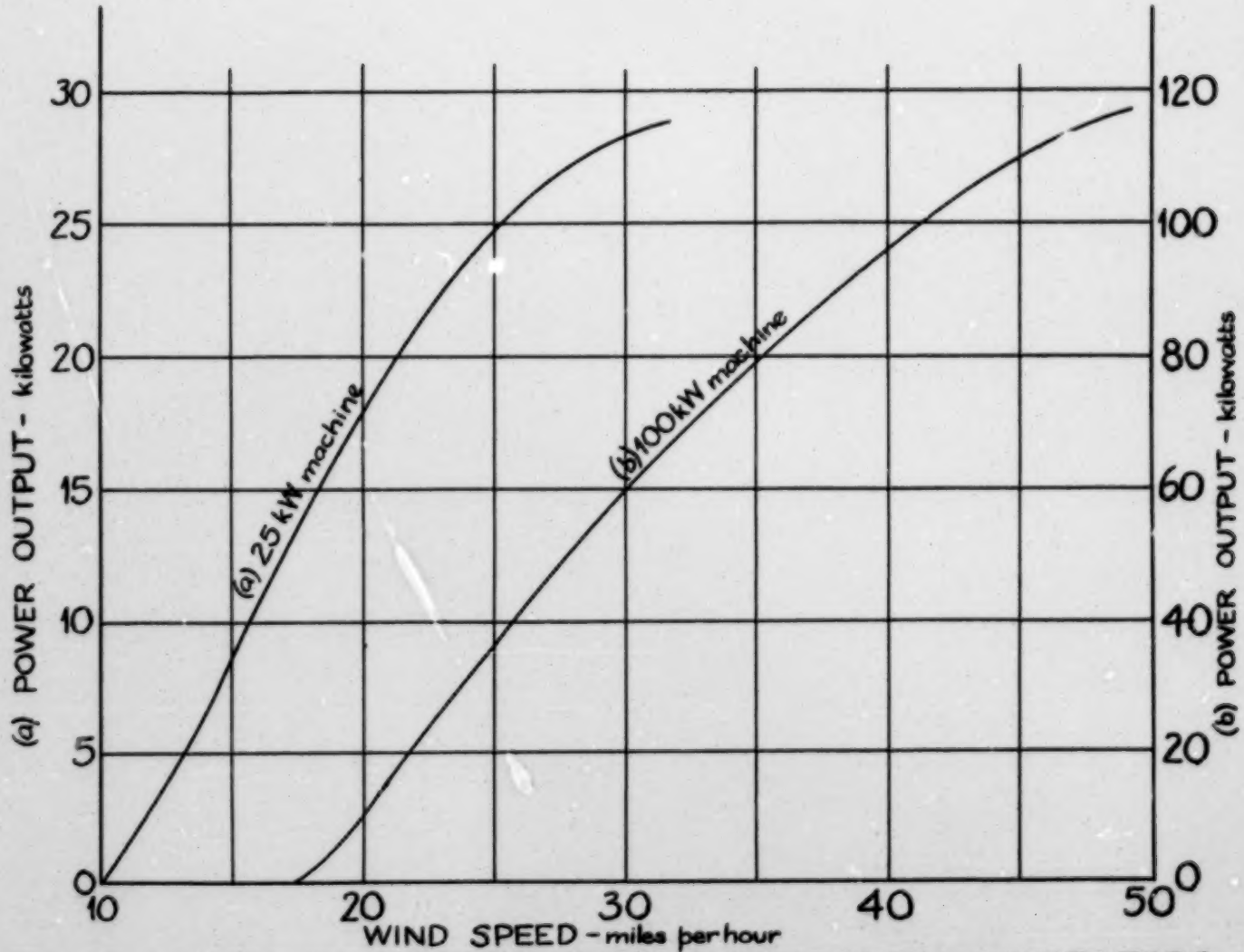

Fig. I. OUTPUT CURVES OF 2 WIND-DRIVEN GENERATORS

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